Renewable and Sustainable Energy Reviews 18 (2013) 595–606

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Possible impact of 2020 bioenergy targets on European Union land use. A scenario-based assessment from national renewable energy action plans proposals

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ARTICLE INFO

Article history:
Received 12 June 2012
Received in revised form
22 October 2012
Accepted 27 October 2012
Available online 3 December 2012

Keywords:
Bioenergy
Biofuels
Land use
National renewable energy action plans
Co-products

ABSTRACT

According to the renewable energy directive 2009/28/EC, the European Union Member States should increase by 2020 the use of renewable energy to 20% of gross final energy consumption and to reach a mandatory share of 10% renewable energy in the transport sector. This study aims to quantify the impact of 2020 bioenergy targets on the land use in the EU, based on the projections of the National Renewable Action Plans in four scenarios: Scenario 1. Bioenergy targets according to NREAPs; Scenario 2. Bioenergy targets according to NREAPs, no second generation biofuels; Scenario 3. Bioenergy targets according to NREAPs, reduced import of biofuels and bioliquids; Scenario 4. Bioenergy targets according to NREAPs, high imports of biofuels and bioliquids. This study also considers the credit for co-products generated from biofuel production. The analysis reveals that the land used in the EU for bioenergy would range between 13.5 Mha and 25.2 Mha in 2020. This represent between 12.2% and 22.5% of the total arable land used and 7.3% and 13.5% of the Utilised Agricultural Area (UAA). In the NREAPS scenario, about 17.4 Mha would be used for bioenergy production, representing 15.7% of arable land and 9.4% of UAA. The increased demand from biofuels would lead to an increased generation of co-products, replacing conventional fodder for animal feed. Considering the co-products, the land used for bioenergy would range between 8.8 Mha and 15.0 Mha in 2020 in the various scenarios. This represent between 7.9% and 13.3% of the total arable land used in the EU and 4.7% and 8.0% of the UAA. In the NREAPS scenario, when co-products are considered, about 10.3 Mha would be used for biofuels, bioliquids and bioenergy production, representing 9.3% of arable land and 5.6% of agricultural land. This study further provides detailed data on the impact on land use in each Member State.

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1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.10.040

1. Introduction

According to the renewable energy directive (RED) 2009/28/EC [1] on the promotion of renewable energy sources, the European Union Member States should increase by 2020 the share of renewable energy of gross final energy consumption from 8.5% in 2005 to 20% and the share of renewable energy in the transport sector from 1.1% in 2005 to 10% This comes along with the strategic energy policy objective to reduce the greenhouse gas emissions in the European Union by 20% compared to 1990 levels. The new Directive lays down legally binding rather than indicative national targets for the share of renewable energy.

The European Union Member States (MS) had to establish, by 30 June 2010, National Renewable Energy Action Plans (NREAPs), according to a template proposed by the European Commission [2], including national targets for the share of energy from Renewable Energy Sources (RES) in electricity, heating and cooling and transport, and the measures to be taken to achieve these targets. In the NREAPs [3], the EU Member States had to propose two scenarios for energy consumption until 2020: the Reference Scenario, taking into account only the energy efficiency and saving measures adopted before 2009; the Additional Energy Efficiency Scenario, considering all energy efficiency and saving measures adopted after 2009.

The analysis of the National Renewable Energy Action Plans (NREAPs) shows [3–6] that, in the Additional Energy Efficiency Scenario, the share of RES in the gross final energy consumption in the EU is expected to reach 20.7% in 2020. The increase of the MS total gross final energy consumption is expected to be more than double, increasing from 4135 PJ in 2005 to 10,216 PJ in 2020. The NREAPs forecasts show that the expected contribution of bioenergy in EU in 2020 will reach 5821 PJ compared to 2581 PJ in 2005 and 3578 PJ in 2010. Biomass is expected to maintain its major role in RES consumption with 57.0%, followed by wind (17.4%), hydro (12.7%), solar (6.2%), heat pumps (5.0%) and geothermal (1.5%). As indicated in the NREAPs, biomass delivered in 2005 about 5.3% of the gross final consumption and 62.3% of the total renewable energy. The NREAPs estimate that in 2020 about 11.8% of the gross final consumption is expected to be provided from biomass. In 2020, bioenergy will present 17.3% of the EU projected heating and cooling, 6.65 of electricity consumption and 89.9% of renewable energy in transport being the dominant renewable energy source.

Biomass availability is a critical issue for the bioenergy production. Competition between alternative use of biomass for food, feed, fibre and fuel is a major concern for bioenergy deployment, as well as the environmental implications related to biofuels [7]. New technologies for the production of lignocellulosic biofuels could also lead to competition between transport fuel and heat and power applications. A comprehensive monitoring of available biomass resources in relation with the biomass demand is needed, taking into account various sustainability constraints and competitive uses.

The 2020 bioenergy targets are likely to have a strong impact on land use and agricultural markets [8–10]. This paper looks into the possible impact of 2020 bioenergy targets on European Union land use based on the projections made by the NREAPs and proposes four possible scenarios for achieving bioenergy targets. The study considers the contribution of biomass (production for electricity, heating and cooling and of biofuels used in transport. The biofuel production would lead to an increased generation of co-products, such as Distillers Dried Grains and Solubles (DDGS) protein rich sugar beet pulp and oilseed meals, replacing conventional fodder (soybean meal and grain crops) for animal feed. The effect of the reduction of the land requirements due to the use of co-products from biofuel production for animal feed is also considered in this paper.

2. Bioenergy and land use

The area used worldwide for biofuel production is expected to increase from 4 Mha in 2000 (less than 1% of the total area of wheat, maize, sugar cane and oilseeds) to 35 Mha in 2020 (about 6%), assuming default developments [11]. A worldwide 10% obligatory blending target for biofuels would require 85–176 Mha of land, depending on feedstock used (food crops or lignocellulosic biomass) and the crop yields [12]. In the European Union, the land requirements for biofuels for meeting the 10% targets in 2020 could range from 17 Mha to 30 Mha, depending on the type of biofuels, the feedstock used and their origin [9]. In the European Union, the amount of available agricultural land can be used for bioenergy production was estimated up to 16 Mha by 2020 [13].

The EU RED excludes several land categories, with high biodiversity value from being used for biofuel production: (a) primary forests and other wooded land; (b) areas designated for nature protection or for the protection of rare, threatened or endangered ecosystems or species; (c) highly biodiverse grassland. Biofuels should not be made from material from peatland and land with high carbon stock, such as: (a) wetlands; (b) continuously forested areas; (c) land covered by trees higher than five metres and a canopy cover between 10% and 30%. The European Commission [14] recommends that the same requirements laid down in the RED for biofuels and bioliquids should also apply for solid and gaseous biomass used in electricity, heating and cooling. Biomass should not therefore be sourced from land converted from forest or other areas of high biodiversity or high carbon stock.

Although biofuels production provides new opportunities for employment, income generation and rural development, there are environmental, social and economic concerns associated with biofuels production. Serious concerns rose about the negative environmental impact of first-generation biofuels: land use changes and damage to biodiversity, impact on food availability and the real greenhouse gas emission reduction [15–17]. Numerous Life Cycle Assessment (LCA) studies have been conducted on the impact of biofuels, with wide range of results in terms of energy balance and GHG emissions [18,19].

Biofuels made from food crops might increase competition for resources (land, labour, capital) with food production, apart from direct competition for food. This might lead to adverse effects on prices and availability of food, feed and bio-based materials [11,12,20,21]. The food price crisis of 2008 opened a hot debate on the biofuels effects. Several studies showed that that the price increases were due to several factors, such as crop supply and demand, macroeconomic factors and biofuels production [22,23].

Land use change impacts can either negative or positive, depending on management practices [24,25]. The impact of bioenergy production on land use can be lowered through higher yields or using co-products from biofuel production as animal feed [26]. The use of biomass from various waste and residues also reduce the land footprint of bioenergy production. Advanced biofuels, based on non-food feedstocks, might have a lower impact on land use due to higher yields compared to biofuel crops [24,25,27]. Although lignocellulosic biofuels offer certain biodiversity advantages, there is no certainty about their better performance compared to first generation biofuels [17]. High yields have been reported in trials in which water and nutrients are non-limiting factors [18], which are much higher than the yields obtained under economically-constrained field conditions [28]. Biomass production on set-aside, marginal and degraded land can be an option to avoid competition for cropland, reduce land use change risks and avoid loss of biodiversity [24,29,30]. Low-quality soils will have lower crop yields, therefore

demanding more land. Cultivation of such land would require large amounts of inputs, including water and nutrients, which might impact on the economics of the biofuels production [12].

In addition to Direct Land Use Changes (dLUC) on the site of a farm or plantation, Indirect Land Use Changes (iLUC) might occur through the displacement of the previous crop to another location. The Indirect Land Use Changes (iLUC) effects vary according to the feedstock, with a high degree of uncertainty [31–33]. The results vary widely due to different modelling assumptions, including feedstock type, land use expansion vs. yield increase, land use dynamics [33,34].

Preventing undesired land use changes requires a sustainable land management policy and adequate tools that identify and prevent them. Land use planning can contribute to preventing conflicts between competing uses of land for food, feed, fibre or fuel, and can be used for ensuring sustainability of biofuels production [35]. A sensitive issue is the protection of so-called no-go, highly sensitive areas, which requires widely accepted criteria and a robust mechanism to prevent land use changes [36].

3. Methodology and scenarios for the assessment of land use impact

3.1. Methodology

This study aims to evaluate the impact of the bioenergy targets on land use in the EU up to 2020. However, it does not aim to look into the impact of the imported biofuels in different forms on the international market, or price impacts on agricultural products. Four scenarios are proposed in this study for the estimation of various impacts of bioenergy and biofuels on European land use.

The assessment is based on the NREAPs projections made by the Member States on the expected bioenergy developments (electricity, heating and cooling and biofuels in transport), for the shares of various biofuels and the availability of domestic biomass from forestry, agriculture and waste sectors. Additional import of solid biomass or biofuels and bioliquids might occur to reach the forecasted demand for the bioenergy targets. Several assumptions are made on the availability of second generation biofuels and bioliquids and on the share of imported biofuels and bioliquids, based on the NREAPs projections.

The NREAPs provide the expected gross final consumption of energy from renewable sources (electricity, heating and cooling and transport). As a baseline, this study considers that the bioenergy targets, as proposed in the NREAPs for 2020 by all MS, are met. The gross inland consumption of biomass is determined in this study on the basis of the expected gross final energy consumption of biomass for electricity production, in heating and cooling and in transport sector, taking into account the efficiency of energy conversion. Based on this information, the biomass feedstock from different sources is estimated. In order to identify the potential gaps in supply that can be covered by import or additional measures for increasing biomass mobilisation, the gross inland biomass consumption is compared with the domestic biomass resources expected to be available and the biomass potential. The land requirements for biomass expected to be available from agricultural land, including biofuels and bioliquids crops, Short Rotation Forestry/Short Rotation Coppice (SRF/SRC) and energy grasses are estimated for all Member States. The estimation of land requirements also includes the credit for the co-products. The main steps of the methodology are:

- Assessment of biomass demand (requirements) to reach the NREAPs targets for electricity, heating and cooling and transport, differentiated by: solid biomass; biogas; bioliquids; biofuels for transport.
- Estimation of the biomass feedstock for bioenergy: solid biomass (direct or indirect wood, residues and by-products from agriculture, SRC, municipal solid waste, industrial waste), biogas (manure, waste, silage maize); biofuels and bioliquids (starch and sugar crops, oilseeds crops, SRF/SRC, by-products).
- Assessment of the land requirements to produce biomass feedstock, depending on the biomass yields, based on the conversion efficiency, biomass yields and credit for co-products.

Current production of agricultural crops, present and forecasted farming practices and conversion efficiencies for biofuels and bioenergy are taken in consideration in the assessment. The use of various by-products and residues from forest and agriculture, as well as waste, with no land-use impact, is also considered. The rationale for the whole assessment is based on the prioritisation of the use of various biomass resources. Thus, biomass is expected to come firstly from waste, as well as residues and by-products from forestry and agriculture, which can contribute significantly to biomass supply [37,38]. When necessary, agricultural crops are expected to provide the additional biomass for bioenergy. The upper limit of the biomass to be used is the either the domestic biomass supply forecasted in the NREAPs, or the biomass potential we estimated for manure, black liquor and straw sources [39]. When one or another of the two limits are reached, another source of biomass could be used, or biomass could be provided from import.

This study considered that solid biomass used for electricity, heating and cooling should come from the following feedstock sources: wood residues from forestry and wood industry; residues and by-products from agriculture; biodegradable fraction of Municipal Solid Waste (MSW) and industrial solid waste; SRF/SRC and energy grasses. The biofuels and bioliquids production was assumed to come from the following sources: by-products and residues from agriculture and forestry; agricultural crops; SRF/SRC and energy grasses. Biogas production might come from: agricultural by-products or processed residues and by-products (manure, animal fat); landfill gas; sewage sludge; silage maize.

The feedstock mix used in the assessment for the production of biofuels and bioliquids was based on the current mix of feedstock, e.g., vegetable oil, derived from oilseed crops (e.g., rapeseed, soy, sunflower, etc.), used oil or animal fat for biodiesel; and wheat, maize, barley, sugar beet and residues from raw alcohol for bioethanol: a differentiated crop mix was considered within each European Union Member State, depending on its specific current and expected agricultural crop production for 2020. The main feedstocks for second generation biofuels, as well as for electricity, heating and cooling, include various wastes and residues from agriculture and forestry (such as wood residues, straw, black liquor), as well as Short Rotation Forestry/Short Rotation Coppice—SRF/SRC (willow, poplar, eucalyptus) and energy grasses (miscanthus and switchgrass).

3.2. Description of scenarios

Based on the NREAPs data, this study proposes four scenarios for the future development of the bioenergy production until 2020. The scenarios assumed that the proposed targets in all Member States and at the EU level for electricity, heating and cooling and transport shall be met. Different options for reaching these targets were proposed and evaluated.

Considering the uncertainties related to the commercial availability of second generation biofuels, two options are considered in this assessment. This study considers a possible contribution of

second generation biofuels according to the projections of the NREAPs (8.9% of biofuels used in transport in 2020), as well as one scenario where second generation biofuels are not available. The expected second generation biofuels would be replaced by first generation biofuels (bioethanol of biodiesel) coming from imports. The main sources for second-generation biofuels would be by-products and residues from agriculture or energy grasses and short rotation forestry.

Scenario 1. Bioenergy targets according to NREAPs, with second generation biofuels
The baseline scenario assumes that the domestic and imported biofuels and bioliquids production shall be according to the proposals of MS in the NREAPs. The shares of bioethanol, biodiesel and other biofuels shall be also in accordance with the data that MS provided in NREAPs. Bioliquids will be produced from black liquor and vegetable oils and, since no data are given on the bioliquids from import, the scenario assumes the same share of bioliquids is expected to be provided from imports, as in the case of biofuels, depending on the domestic resources. The same share of second generation bioliquids is considered in the calculations as the share of second generation biofuels provided in the NREAPs.

Scenario 2. Bioenergy targets according to NREAPs, no second generation biofuels
This scenario considers the main assumptions from the baseline NREAPs scenario. In this scenario, however, second generation biofuels are not available. In this case, the biofuels expected to originate, in the NREAPs scenario, from second generation, shall be replaced by first generation biofuels coming from imports.

Scenario 3. Bioenergy targets according to NREAPs, reduced import of biofuels and bioliquids, with second generation biofuels
This scenario considers the main assumptions from the baseline NREAPs scenario. In addition, a reduced amount of biofuels and bioliquids from import is considered, representing 50% of the import of biofuels proposed in the NREAPs. The second generation biofuels should be produced according to the forecast of the NREAPs.

Scenario 4. Bioenergy targets according to NREAPs, high imports of biofuels and bioliquids, with second generation biofuels
This scenario considers all assumptions from the baseline NREAPs scenario. In this scenario, however, a higher import is considered, representing 150% of the proposed import of biofuels in the NREAPs scenario. The second generation biofuels and bioliquids should be produced according to the NREAPs scenario.

4. Analysis of the biomass demand and supply

4.1. Projections of bioenergy developments

The NERAPs reported the expected bioenergy production in EU for 2020 including solid biomass, biogas and bioliquids[1] for electricity, heating and cooling production and biofuels for transport. The plans provides the share of the electricity produced in Combined Heat and Power and electricity-only plants, as well as the data on heating and cooling delivered in district heating and the biomass used in households. The forecasted increase of the MS total gross final energy consumption of biomass in electricity, heating and cooling and transport in the EU, in comparison with renewable energy consumption is presented in Table 1. The Member States expect to more than double their total gross final energy consumption of renewable energy from 4133 PJ in 2005 to 10,216 PJ in 2020. The RES share is expected to reach 34% in electricity sector, 11.7% in transport sector and 21.4% in heating and cooling sector. The bioenergy presents a share of 57% of total renewable energy use in 2020 with a decrease from 62% in 2005, according to the aggregated data of NREAPs [3–6].

Table 1
Expected growth of final energy from biomass in electricity, H&C and transport in the EU [PJ].
Source: Aggregated data from NREAPs [3].

	2005	2010	2015	2020
Solid biomass	2,330	2,651	3,182	3,937
Biogas	71	165	271	418
Bioliquids	54	185	219	255
Biofuels	125	577	820	1,210
Total biomass	2,581	3,578	4,492	5,821
RES	4,139	5,748	7,602	10,216
Biomass share of RES	62.3%	62.3%	59.1%	57.0%
Gross final energy consumption	48,631	49,570	49,582	49,389
Biomass share in gross final consumption	5.3%	7.2%	9.1%	11.8%

The total use of biomass electricity, heating and cooling and biofuels in transport is estimated to increase from 2581 PJ in 2005 to about 5821 PJ as final energy in 2020, including biofuels with 1210 PJ. Overall, the share of bioenergy in the gross final energy consumption will increase from 5.3% in 2005 to about 11.8% in 2020, according to the NREAPs forecast. This means that this will result in a significant increase in the use of biomass in the EU energy sector. The most significant increase is expected from biofuels for transport (from 125 PJ in 2005, 577 PJ in 2010 to 1210 PJ in 2020). However, other sources will also experience high growth, such as biogas (increase from 71 PJ in 2005 to 165 PJ in 2010 and 418 PJ in 2020) and bioliquids used for electricity, heating & cooling (from 54 PJ in 2005, 185 PJ in 2010 to 255 PJ in 2020).

According to NREAPs, the contribution of RES to electricity in 2020 is expected to be 1217 TW h. The share of RES in the electricity consumption is forecasted to be grown from 15% in 2005 to 34% in 2020. The contribution to electricity made by bioenergy should be 231,965 GW h in 2020, representing about 19.4% of RES electricity. The biomass electricity is expected to increase from 69,039 GW h produced in 2005 to 231,965 GW h in 2020. The main contribution to electricity will come from solid biomass with 155,246 GW h, biogas with 63,972 GW h and bioliquids with 12,747 GW h of electricity in 2020. High increase is expected from electricity produced from bioliquids (from 1470 GW h in 2005 to 12,747 GW h in 2020), biogas (from 12,428 GW h in 2005 to 63,972 GW h in 2020), solid biomass electricity (from 55,087 GW h in 2005 to 155,246 GW h in 2020). A share of renewable electricity (54.7% of bio-electricity) or 126,936 GW h will be produced by means of CHP in 2020. In comparison, an amount of 34,918 GW h of electricity was produced in CHP plants in 2005 (50.6% of bio-electricity) [3–6]. The expected production of electricity from biomass in different European Union Member States in 2020 is shown in Fig. 1.

Almost 50% of the total energy consumed in Europe is used for heat generation every year, either for domestic or industrial purposes. The heating and cooling sector is expected to contribute substantially towards the achievement of the EU renewable energy and GHG reduction targets. Based on NREAPs, the renewable energy share in heating and cooling consumption in EU is expected to increase from 9.9% in 2005% to 21.4% in 2020. The

[1] Bioliquids are defined in the Renewable Energy Directive 2009/28/EC as liquid fuel produced from biomass for energy purposes other than for transport, including electricity and heating and cooling.

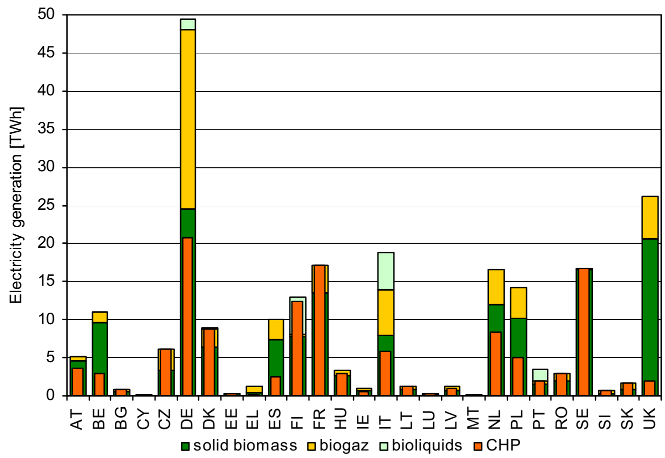

Fig. 1. Expected biomass electricity generation in the EU in 2020.
Source: [3].

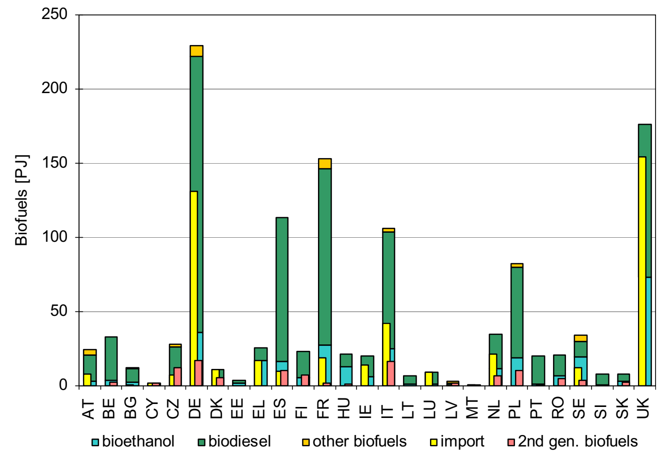

Fig. 3. Planned biofuels use in transport sector in 2020. .
Source: aggregated data from NREAPs [3].

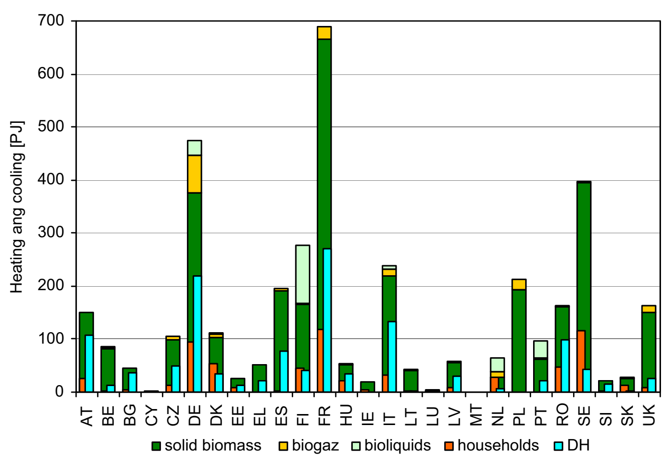

Fig. 2. Expected biomass use in heating & cooling in the EU in 2020.
Source: [3].

proposed target will mean an increase in the use of heating and cooling from biomass from 2207 PJ in 2005 to 3775 PJ in 2020, representing a share of 17.3% of heat demand.

Biomass should have the major contribution in renewable heating and cooling in 2020, with a share of 81.0% followed by heat pumps (10.6%), solar (5.7%) and geothermal (2.4%). Although the biomass heating and cooling generation is expected to experience a growth of 60% between 2005 and 2020, its share in RES heating will decrease from 97% in 2005 to 81% in 2020. The most important increase in the biomass heating is expected to come from biogas with 26 PJ in 2005, to 62 PJ in 2010 and 187 PJ in 2020. In biomass heating and cooling, solid biomass will provide 3379 PJ, biogas will provide 187 PJ and bioliquids will provide 209 PJ in 2020. A small part of the heating and cooling is expected to be provided by district heating and cooling in 2020, with about 745 PJ and a significant increase compared with 229 PJ in 2005. Biomass used in households, mainly used in the form of fuel wood and wood pellets is expected to increase to a limited extent (26%) to 1479 PJ [3–6]. Significant variations between MS are visible in the expected use of biomass in heating and cooling in 2020 (Fig. 2).

The NREAPs analysis reveals that in EU the RES share in the energy used in transport will increase to about 11.7% in 2020 compared to 1.4% in 2005. This value is above the 10% binding target established by the Directive 2009/28/EC. In 2020 the biofuels used in transport are expected to represent 11.8% of the renewable energy in use having the highest share in bioenergy with 89.9% of RES in transport. In 2020, the greatest contribution is expected from biodiesel with 873 PJ (72.2%), followed by bioethanol/bio-ETBE with 306 PJ (25.3%) and other biofuels (biogas, vegetable oils etc.) with 31 PJ (2.6%). The first-generation biofuels present 91.1% of all biofuels projected to be used. The use of biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material (biofuels defined in article 21.2 in the Directive 2009/28/EC as biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material) is expected to reach 107 PJ and a share of 8.9% of the biofuel use in the EU in 2020 [3–6].

A significant share of biofuels to be used in the EU in 2020 is expected to be imported. The NREAPs estimates that, in 2020, about 459 PJ biofuels will be imported, representing 37.9% of the biofuel used in transport. Apart from this, some raw material is expected to be imported and then processed within the EU. It is, however, not clear in the NREAPs documents whether imports come from internal EU trade or from third countries, thus increasing the uncertainty about the land requirements in the EU. However, there are significant differences between MS in terms of the share of domestic and imported biofuels, considering the availability of biofuels made from waste, residues and lingo-cellulosic feedstock (Fig. 3).

4.2. Estimation of biomass demand

Biomass availability is of significant importance for meeting 2020 RES targets. Biomass mobilisation is a key issue, especially where the biomass demand is close to the sustainable potential. Therefore, the first objective of this study is to establish the biomass requirements to meet the bioenergy targets throughout the EU and the main sources for biomass (domestic vs. import) and type of biomass (from forestry, agricultural crops, residues from forestry and agriculture and waste). The biomass was allocated to different sources and different purposes (biomass and bioliquids for electricity, heating & cooling and biofuels), considering the expected use and availability of solid biomass, biogas, bioliquids and biofuels.

The total primary biomass demand was estimated in each MS, depending on the existing biomass potential in each MS and the NREAPS projections on bioenergy production in electricity, heating and cooling and in transport sector. The use of biomass in various sectors was considered, such as the share of electricity in Combined Heat Power and electricity only plants; biomass in heating and cooling, in District Heating (DH) as well as in

households. The quantification of the biomass demand was done for the following categories: solid biomass; biogas; bioliquids; and biofuels.

In the calculations, we considered as final heat consumption the energy content of biomass before conversion when used in households, services and industry and the energy content of heat after conversion when used in District Heating (DH) and Combined Heating Power (CHP) plants. Many different conversion technologies are available, but detailed information on the type of technologies likely to be deployed until 2020 as well as the plant capacities is not available, since their deployment depends on the market, the local biomass resources and local energy demand (for heat production). Considering the variety of biomass feedstock available, technologies and the wide range of plant capacities that can be used for bioenergy production, and average conversion efficiency for solid biomass, biogas and bioliquids is considered [40–43] as well as some increase in the conversion efficiency between 2005 and 2020 (Table 2).

The biomass feedstock demand for each MS to produce bioenergy for solid biomass; biogas; bioliquids; biofuels is established based on the template for NREAPs. The analysis of NREAPs show that total biomass primary demand is expected to increase from 3094 PJ in 2005 to 7379 PJ in 2020 (138% increase). The major part is expected to come from solid biomass, with 4947 PJ (67.0% of total biomass), followed by biofuels with 1210 PJ (16.4%), biogas with 883 PJ (12.0%) and bioliquids with 338 PJ (4.6%). Table 3 shows the total biomass primary demand in the EU to meet the targets for electricity, heating and cooling and in transport in the EU estimated for solid biomass, biogas, bioliquids and biofuels.

Different studies are available on the biomass potential in EU. The European Environment Agency [13] estimated the available potential of biomass for EU (Bulgaria and Romania are not included) at 9839 PJ from forestry (16.7% of potential), 4007 PJ from agriculture (40.7% of potential) and 4181 PJ from waste (42.5% of potential). Another study, performed by the Biomass Futures project [44], shows that the biomass sustainable potential might be even larger in the EU in 2020, reaching 15,686 PJ, of which 7006 PJ from forestry (44.7%), 6604 PJ from agriculture (42.1%) and 2076 PJ from waste (13.2%).

Table 2
Conversion efficiency for bioenergy production.
Source: [40–43].

Source	Plant type	2005	2010	2015	2020
Solid biomass	CHP	0.24	0.24	0.25	0.26
	Electricity only	0.26	0.26	0.27	0.28
Biogas	CHP	0.27	0.28	0.29	0.30
	Electricity only	0.30	0.30	0.31	0.32
Bioliquids	CHP	0.28	0.28	0.29	0.30
	Electricity only	0.30	0.30	0.31	0.32

Table 3
Expected trend in biomass primary demand to meet the bioenergy targets in the EU [PJ].

	2005	2010	2015	2020
Solid biomass	2590	3247	3969	4947
Biogas	176	403	616	883
Bioliquids	202	246	289	338
Biofuels	125	577	820	1210
Total	3094	4473	5694	7379

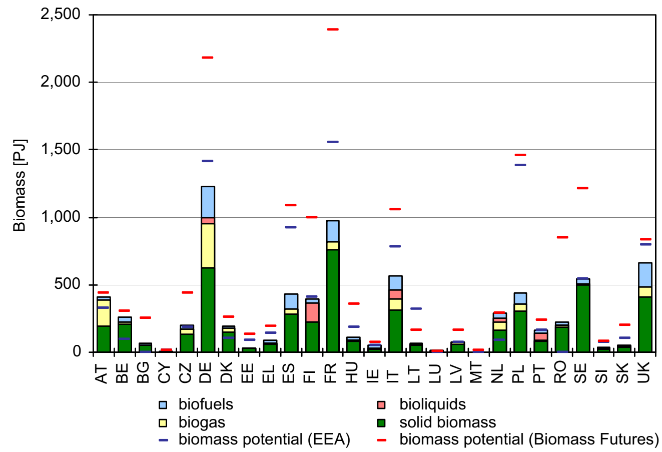

Fig. 4. Primary biomass demand and the estimated biomass potential.

Thus, according to both studies, the biomass potential of the EU is large enough to ensure the biomass we expect to be needed to reach the bioenergy targets at the EU level. The increase in the biomass demand and the available potential shows that further development of bioenergy in the European Union is possible, especially in some MS. However, some biomass is expected to be imported, even if biomass potential is higher than the expected demand in 2020. Fig. 4 shows the expected primary biomass demand in all MS, based on national predictions for bioenergy production, in comparison with the biomass potential estimated by the above mentioned studies. The comparison reveals the extent of the utilisation of domestic biomass potential in different MS in 2020 and the extent to which some MS could increase their contribution of to energy production.

The analysis reveals that the biomass demand is higher than the biomass potential in several MS as Belgium, Denmark and Netherlands, which means that these countries should rely on high extent on imports. In other MS, such as Czech Republic, Ireland, Latvia and Portugal, the expected biomass demand in 2020 is quite close to the potential. However, the biomass sustainable potential, provided by the Biomass Futures study, is significantly higher than the biomass potential provided by EEA and all MS can rely on domestic biomass to reach their bioenergy and biofuels targets for 2020.

4.3. Biomass demand and domestic supply

The NREAPs provide an estimate of the expected supply of domestic biomass in all relevant sectors (forestry, agriculture and waste). The biomass feedstock sources are further detailed as follows: solid biomass: direct or indirect wood, residues and by products from agriculture, SRF/SRC and energy grasses, municipal solid waste, industrial waste; biogas: manure, waste, silage maize; biofuels and bioliquids: starch and sugar crops, oilseeds crops, SRF/SRC, by-products.

The domestic biomass supply in the EU in 2020 is expected to increase from around 3695 PJ in 2006 to around 5542 PJ in 2020, in order to meet the demand for heat, electricity and transport biofuels. The analysis shows that domestic biomass supply in 2020 should come from forestry with 3136 PJ, from agriculture with 1675 PJ and from waste 731 PJ. While the forest based biomass is expected to maintain its major role to biomass supply until 2020 (57%), the major increase in supply should come from agriculture (with more than 150% increase compared with 2006).

The expected gross inland biomass consumption is compared with the domestic biomass resources expected to be available and

Table 4
Biomass domestic supply in the EU [PJ].
Source: Aggregated data from NREAPs [3].

	2006	2015	2020
Forestry			
direct wood	1264	1545	1807
indirect wood	1382	1260	1329
Agriculture			
crops	410	581	803
by-products	241	580	872
Waste			
MSW	313	329	433
industrial waste	46	192	255
sewage sludge	39	34	43
Total	3695	4520	5542

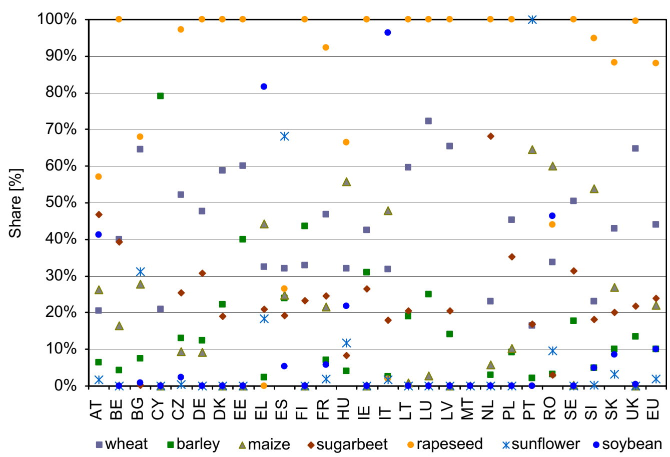

Fig. 5. Share of different feedstocks for biofuels in 2020.

the biomass potential, as provided in the NREAPs (Table 4). This is used to identify the potential gaps in supply that can be covered by import or additional measures for increasing biomass mobilisation. The difference between biomass domestic supply and biomass demand could come as imports of biofuels and bioliquids as well as solid biomass (wood residues, wood pellets, etc.).

The study assumes that biomass demand will be met firstly from waste, residues and various by-products from forestry, agriculture and waste, which is feedstock without land requirements. In case more biomass is needed, some agricultural land might be used to produce additional biomass, and thus the feedstock produced from agricultural land was calculated (feedstock with land footprint). Some biomass is also expected to be imported, depending on the scenario, in order to meet the demand.

First generation, domestic biodiesel production in the EU is expected to be produced mainly from rapeseed (88%), soybean (10%) and sunflower (2%). Also, domestic bioethanol should come, at EU level, mainly from wheat (44%), rye and barley (10%), maize (22%) and sugarbeet (24%), according to the Fapri agricultural outlook [45]. This study made the allocation of feedstock for biofuel production in the EU Member States based on the projections made for the use of different feedstock at the EU level in 2020 [45] and the production of different crops in each Member States, according to national conditions. The result of the calculation of the share of different feedstock for first generation biofuels in 2020 are shown in Fig. 5.

The contribution of different crop for biofuels production was then estimated in each EU Member State. The analysis reveals

Table 5
Total demand for biomass cultivated on agricultural land [tonnes].

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Domestic				
Cereals	12,355,233	12,355,233	19,189,091	8,500,994
Sugar crops	13,917,455	13,917,455	23,432,420	8,791,273
Oilseeds	34,809,104	34,965,023	54,007,629	24,142,740
Sillage maize	18,268,291	18,487,032	17,749,538	17,733,895
SRC/SRF	12,581,664	12,884,095	16,800,485	15,871,947
Imported				
Sugarcane	84,375,645	98,331,815	42,187,822	107,176,501
Soybean	8,003,082	9,391,012	3,982,345	10,493,725
Palm oil	51,832,320	59,362,785	25,873,146	69,273,383

that, in comparison with an average (for 2001–2010) cereal production (rice excluded) in the EU of around 284 Mt, between 8.3 Mt and 19.5 Mt cereals would be required for bioenergy production in 2020, representing between 2.9% and 6.9% of the cereal production in the EU. Also, the use of sugar beet for bioethanol production would require between 8.1 Mt and 23.1 Mt, compared to an average production in the EU of about 122 Mt. Between 24.6 Mt and 53.4 Mt oilseeds would be required for biofuels and bioliquids production in the proposed scenarios, while the average EU production of oilseeds is about 23 Mt. This means that the production of oilseeds must rise significantly (increase of 70–132% needed) to cover the demand for biofuels and bioliquids alone. The demand for feedstock from energy grasses/SRF/SRC should be also significant, between 11.9 Mt and 15.7 Mt dry biomass. The use of crops for the production of silage maize should also increase to around 17.7–18.5 Mt (as compared with 176 Mt average production for 2001–2010 in the EU) in order to cover the demand for feedstock, in addition to the use of manure, other residues, landfill gas or sewage sludge for biogas production. Table 5 shows the total demand of biomass cultivated on agricultural land, which is needed in the different scenarios.

5. Bioenergy impact on land use

5.1. *Land requirements for bioenergy*

This study provides the estimates the land area required in the four proposed scenarios (see Section 3.2) and the impact on land use in all EU Member States. Land use requirements are estimated depending on the expected domestic production of bioenergy, conversion efficiency, crop mix and yield. The assessment of the land requirements for producing solid biomass, biogas, bioliquids and biofuels considers several crops expected to be used and the common practices for agricultural production in the near future until 2020. The land use requirements are finally compared with arable, grassland and Utilised Agricultural Area (UAA) in each Member State [46]. The main data used in the calculations for the processing of cereals, sugar beet, oilseeds and other feedstock to biofuels and bioliquids as well as to electricity and heating and cooling [48–50] are presented in Table 6.

Since large variations are found in the yields of different crops, this analysis uses the national crop yields for each Member State. The data used are derived from average values of the period 2001–2010 for crop acreage and yields, in order to reflect the yearly variation for each Member State for starch crops (wheat, maize, barley), sugar crops (sugar beet) and oilseeds crop (rapeseed, sunflower, soybean). A moderate yield increase for each crop is considered [47] for the period between 2010 and 2020 in each Member State, as shown in Table 7.

Table 6
Input data for biofuel processing and biogas production in the EU.
Source: [48–50].

	Bioethanol [litre/kg]	Average 2010		Expected 2020	
		Bioethanol yield [litre/ha]	Bioethanol yield [GJ/ha]	Bioethanol yield [litre/ha]	Bioethanol yield [GJ/ha]
Wheat	0.340	1734	37	1859	40
Maize	0.400	2600	56	2679	57
Barley	0.340	1462	31	1552	33
Sugarbeet	0.110	6622	141	7030	150
SRF/SRC	0.300	2700	58	2700	58
	Biodiesel [kg/kg]	Biodiesel yield [kg/ha]	Biodiesel yield [GJ/ha]	Biodiesel yield [kg/ha]	Biodiesel yield [GJ/ha]
Rapeseed	0.370	1147	24	1255	27
Sunflower	0.320	512	11	571	12
Soybean	0.180	468	10	512	11
SRF/SRC	0.200	1800	38	1800	38
	Energy content [mc/dry t]	Biogas yield [mc/ha]	Biogas yield [GJ/ha]	Biogas yield [kg/ha]	Biogas yield [GJ/ha]
SRF/SRC	600	7405	159	7555	162

Table 7
Expected annual increase on crop yields in the EU up to 2020 [%/year].
Source: [47].

	Wheat	Barley	Maize	Silage maize	Sugarbeet	Rapeseed	Sunflower	Soybean
EU15*	0.5	0.5	0.2	0.2	0.5	0.8	0.8	0.8
EU12**	1.1	1.1	0.5	0.5	0.8	1.2	1.2	1.2
EU	0.7	0.7	0.3	0.2	0.6	0.9	1.1	0.9

* EU15: EU Member States before 1 May 2004.
** EU12: EU Member States that joined the EU after 1 May 2004.

Table 8
Land requirements for bioenergy production in the EU under different scenarios (credit for co-products not considered) [ha].

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Cereals	2,257,081	2,257,081	3,388,836	1,616,277
Sugar crops	232,054	232,054	390,754	142,398
Oilseeds crops	12,017,801	12,079,226	17,803,859	8,277,386
Silage maize	1,256,243	1,274,448	1,227,060	1,225,863
Energy crops	1,797,532	1,840,585	2,406,659	2,267,421
Total land requirements	17,560,710	17,683,394	25,217,167	13,529,344
Arable land	110,602,349	110,602,349	110,602,349	110,602,349
Share of arable land	15.9%	16.0%	22.8%	12.2%
UAA	184,657,061	184,657,061	184,657,061	184,657,061
Share of UAA	9.5%	9.6%	13.7%	7.3%
Grasslands	59,078,769	59,078,769	59,078,769	59,078,769
Share of grassland area	29.7%	29.9%	42.7%	22.9%

The scenario analysis reveals that in 2020 the total land used for bioenergy and biofuel production using domestic feedstock would range between 13.5 Mha and 25.2 Mha (Table 8). This represents 12.2% to 22.5% of the total arable land used in the EU and 7.3% to 13.5% of the total Utilised Agricultural Area (UAA). The Utilised Agricultural Area is defined [46] as the total area taken up by arable land, permanent pasture and meadow, land used for permanent crops and kitchen gardens. In fact, the biofuel and bioenergy production might require this land area in addition to the present land use for agriculture, either through the release of land which is not needed anymore, either through the expansion of arable land on grasslands and UAA.

This expansion of land use can be on agricultural land on the expense of grasslands. In the NREAPs baseline scenario (scenario 1), about 17.6 Mha would be used for bioenergy production (electricity, heating and cooling and biofuels production), representing 15.9% of arable land and 9.5% of agricultural land. Figs. 6 and 7 show the impact of land use for bioenergy in different scenarios in all Member States in 2020. The impact of bioenergy targets, in terms of land use requirements and the share of land used in the Member States, is quite different, both in terms of land requirements and share of UAA. This depends on the expected bioenergy production, the arable area and UAA in each Member States. Upon NREAPs baseline scenario the land use

would reach up to 2.8 Mha in France, 2.8 Mha in Germany, 2.6 Mha in Spain and 2.0 Mha in Italy.

5.2. Accounting for co-products

The increased demand for biofuels will significantly increase the area devoted to bioenergy crops. This will be reduced to some extent by the use of co-products from biofuel production for animal feed. This study considers the land use effects associated with the production of co-products. Increased demand from biofuels leads to an increased generation of co-products, such as Distillers Dried Grains and Solubles (DDGS) protein rich sugar beet pulp and oil meals.

The co-products from biofuel production are used for feed instead of conventional fodder and substitute a mix of soybean meal and grain crops. The credit for each by-product and the land released were established, considering the ratio of co-products generated, corresponding to the feedstock used and biofuel produced. The main ratios [48] used in the calculation of co-products are provided in Table 9.

An important issue for accounting for the land use credit associated with the co-products is the substitution rates. The rates for the substitution of biofuels by-products depend on the carbohydrate and protein content of the by-products and that of equivalent animal feed products which are substituted. In this study, we used the proportion of soybean meal and grain feed the by-products can substitute, as calculated in [48], by balancing total metabolized protein and digestible energy using a mix of soybean and cereals. The sugarcane co-product (bagasse) from ethanol production from sugar cane is used in electricity production. Some energy (heat and electricity) is also produced from the second-generation biofuels. The ratios of energy produced were taken from [48]. Table 10 shows the soy meal and grain feed substitution ratios for each by-product. Tables 10 and 11

In the NREAPS scenario (scenario 1), about 10.4 Mha would be used for bioenergy production, representing 9.4% of arable land and 5.6% of UAA. Table 11 shows the land requirements for bioenergy production in the EU under different scenarios, with credit for co-products are considered. The impacts of 2020 bioenergy targets, in terms of land use requirements and the share of land used in the MS are quite different. Land use requirements for bioenergy would reach up to 2.2 Mha in Germany, 1.5 Mha in Spain and 1.4 Mha in France. Figs. 8 and 9 show the impact of land use for bioenergy in different scenarios in all Member States in 2020, with credit for co-products considered. This change in land use footprint, compared with the situation when co-products were not considered, depends on the different share of biodiesel and bioethanol produced and different mix of feedstock used in different MS.

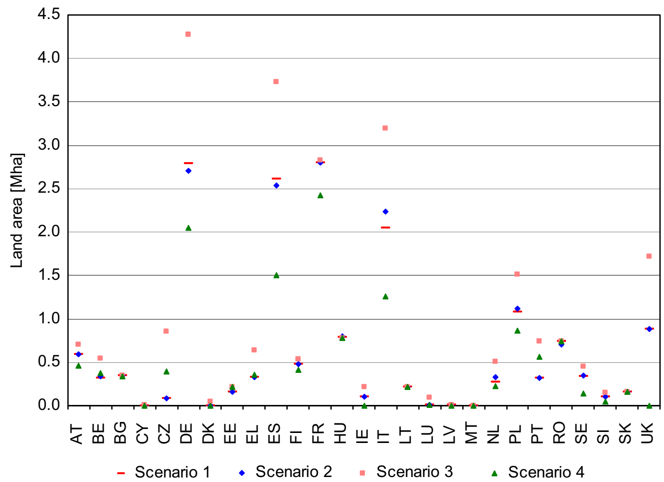

Fig. 6. Land requirements for bioenergy production in the EU in 2020 in different scenarios in 2020 (credit for co-products not considered) [Mha].

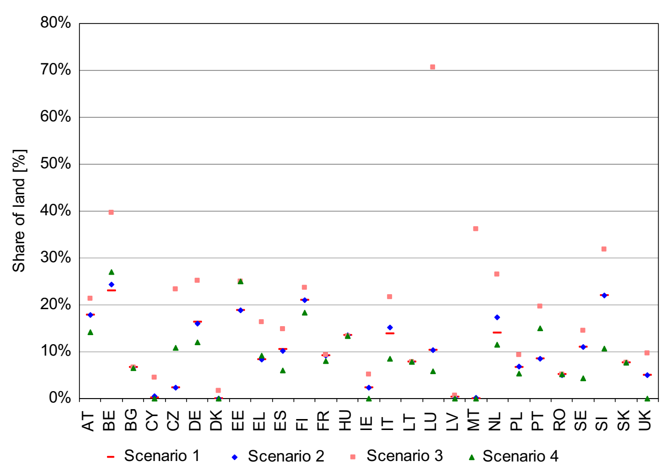

Fig. 7. Share of land requirements for bioenergy production of UAA in the EU in different scenarios in 2020 (credit for co-products not considered).

6. Conclusions

The biomass use for bioenergy production is expected to increase significantly in the EU until 2020. Biomass is expected to maintain

Table 9
Ratio used for accounting for co-products.
Source: [48].

	kg biofuel/kg feedstock	kg co-prod/MJ biof	kg co-prod/kg biofuel	kg co-prod/kg feedstock
Wheat	0.298	0.043	1.161	0.346
Maize	0.302	0.041	1.100	0.332
Barley	0.269	0.043	1.161	0.312
Sugarbeet	0.077	0.028	0.756	0.059
Rapeseed	0.400	0.041	1.469	0.588
Sunflower	0.435	0.036	1.300	0.565
Soybean	0.190	0.118	4.319	0.821
	kg biofuel/kg feedstock	MJ/MJ biofuel	MJ/kg biofuel	MJ/kg feedstock
Lignocellulosic BTL	0.234	0.045	1.980	0.463
Lignocellulosic ethanol	0.269	0.099	2.673	0.718

Table 10
Substitution rates for co-products of biofuels.
Source: [48].

	Dry feed wheat replaced	Dry soybean meal replaced	Wet feed wheat replaced	Wet soybean meal replaced
Soy meal	0.954		0.976	
Rapeseed meal	0.480	0.377	0.497	0.382
Sunflower meal	0.537	0.212	0.556	0.215
Maize DDGS	0.761	0.251	0.813	0.262
DDGS feed meal	0.716	0.290	0.766	0.303
Dried sugar beet pulp	0.828	0.013	0.866	0.013
Palm kernel meal	0.686	0.117	0.710	0.118

Table 11
Land requirements for bioenergy production in the EU under different scenarios, with credit for co-products [ha].

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Cereals	1,446,467	1,446,467	2,170,490	1,035,814
Sugar crops	220,120	220,120	370,657	135,074
Oilseeds crops	5,675,904	5,737,093	8,775,233	4,107,121
Silage maize	1,256,243	1,274,448	1,227,060	1,225,863
Energy crops	1,797,479	1,840,585	2,406,601	2,267,368
Total land requirements	10,396,212	10,518,712	14,950,041	8,771,241
Arable land	110,602,349	110,602,349	110,602,349	110,602,349
Share of arable land	9.4%	9.5%	13.5%	7.9%
UAA	184,657,061	184,657,061	184,657,061	184,657,061
Share of UAA	5.6%	5.7%	8.1%	4.8%
Grasslands	59,078,769	59,078,769	59,078,769	59,078,769
Share of grassland area	17.6%	17.8%	25.3%	14.8%

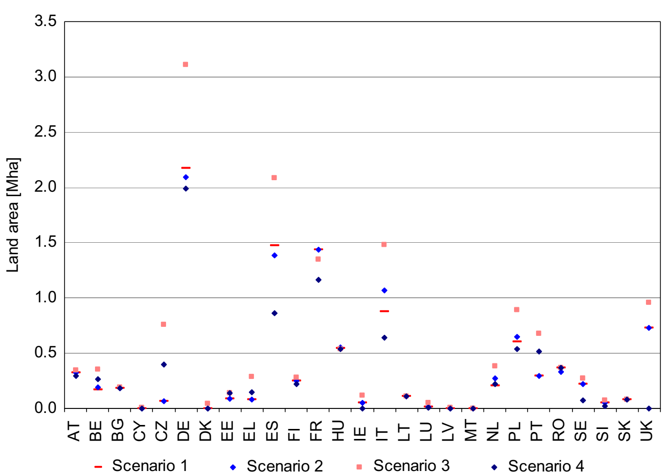

Fig. 8. Land requirements for bioenergy production in the EU in 2020 in different scenarios (credit for co-products considered).

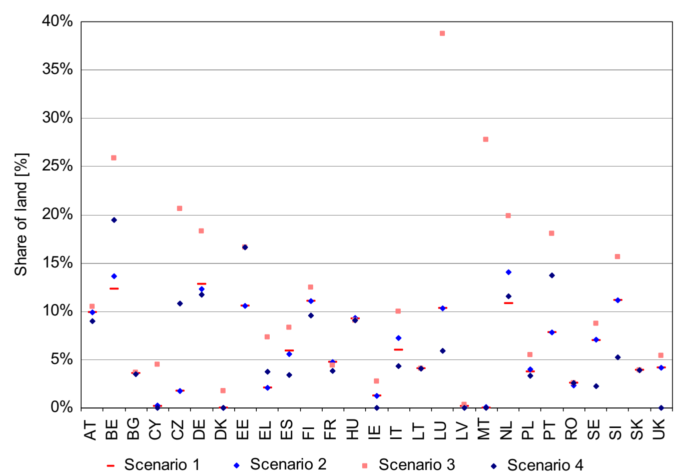

Fig. 9. Share of land requirements of bioenergy production of UAA in the EU in 2020 in different scenarios (credit for co-products considered).

its leading position as compared to other renewable energy sources in the EU. Bioenergy production would require land area in addition to the present land use for agriculture, either through the release of land which is not in production anymore, either through the expansion of arable land on agricultural land.

Biomass is expected to maintain its major role in RES consumption with 57.0%, followed by wind (17.4%), hydro (12.7%), solar (6.2%), heat pumps (5.0%) and geothermal (1.5%). Biomass will remain the dominant technology for the heating and cooling sector, with 17.4% of heating and cooling consumption, followed by heat pumps with 2.3%, solar thermal with 1.2% and geothermal with 0.5%. Biofuels will represent the major RES in transport, with 89.9% in 2020, while having a significant increase from 125 PJ in 2005 to 1210 PJ in 2020. The use of biofuels from wastes, residues and lignocellulosic material is expected to reach 107 PJ and a share of 8.9% of the biofuel use. A significant share of biofuels is expected to be imported in the EU, about 463 PJ biofuels, representing 37.9% of the biofuel use in 2020.

The analysis of the impact of the bioenergy (electricity, heating and cooling and transport) target on land use in EU up to 2020 is based on four scenarios derived from the National Renewable Energy Action Plans: Scenario 1. Bioenergy targets according to NREAPs; Scenario 2. Bioenergy targets according to NREAPs, no second generation biofuels; Scenario 3. Bioenergy targets according

to NREAPs, reduced import of biofuels and bioliquids; Scenario 4. Bioenergy targets according to NREAPs, high imports of biofuels and bioliquids.

All scenarios assume that the proposed targets in all MS and at the EU level for electricity, heating and cooling and transport shall be met. The gross inland consumption of biomass was established on the basis of the expected gross final energy consumption of biomass in electricity, in heating and cooling and in transport sector, depending on specific efficiencies of energy conversion. Total biomass primary demand is expected to increase from 3094 PJ in 2005 to 7379 PJ in 2020. The major part is expected to come from solid biomass, with 4947 PJ, followed by biofuels with 1210 PJ, biogas with 883 PJ and bioliquids with 338 PJ.

The study reveals that the biomass potential of the EU is large enough to ensure the biomass demand for reaching the proposed bioenergy targets. However, some biomass is expected to be imported, either as biofuels and bioliquids, as well as solid biomass (wood residues, wood pellets, etc.), even if biomass potential is higher than the expected demand. The increase in the biomass demand and the available potential shows that further development of bioenergy in the European Union is possible, especially in some Member States. Biomass mobilisation is a key issue, especially where the biomass demand is close to sustainable potential and in countries with fragmented ownership.

The land use requirements in the EU were estimated depending on the expected domestic production of bioenergy, biofuels and bioliquids, conversion efficiency of bioenergy, crop mix and yield. The assessment of the land requirements for producing solid biomass, biogas, bioliquids and biofuels considered several crops expected to be used and the common practices for agricultural production in the near future until 2020.

The additional demand for biofuels and bioliquids would require a strong increase in imports, as expected in the NREAPS. The total land used for bioenergy in the European Union would range between 13.5 Mha and 25.2 Mha in 2020 in the various scenarios. This represent between 12.2% and 22.8% of the total arable land used in the EU and 7.3% and 13.7% of the total Utilised Agricultural Area. In the NREAPS scenario, about 17.6 Mha would be used for bioenergy production, representing 15.9% of arable land and 9.5% of Utilised Agricultural Area. The impacts of bioenergy targets, in terms of land use requirements and the share of land used in the MS are quite different. Thus, the land use would reach up to 2.8 Mha in France, 2.8 Mha in Germany and 2.6 Mha in Spain and 2.0 Mha in Italy.

The increased demand from biofuels would lead to an increased generation of co-products. The co-products from biofuel production are used for feed instead of conventional fodder, reducing to some extent the impact on land use. Considering the co-products generated from biofuel production, the total land used for bioenergy and biofuel production using domestic feedstock would range between 8.8 Mha and 15.0 Mha in 2020 in the various scenarios. This represent between 7.9% and 13.5% of the total arable land used in the EU and 4.8% and 8.1% of the total Utilised Agricultural Area. In the NREAPS scenario, when co-products are considered, about 10.4 Mha would be used for biofuels, bioliquids and bioenergy production, representing 9.4% of arable land and 5.6% of agricultural land. Land use requirements for bioenergy would reach up to 2.2 Mha in Germany, 1.5 Mha in Spain and 1.4 Mha in France, in case credit for co-products are considered.

Country codes.

AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom
EU	European Union

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